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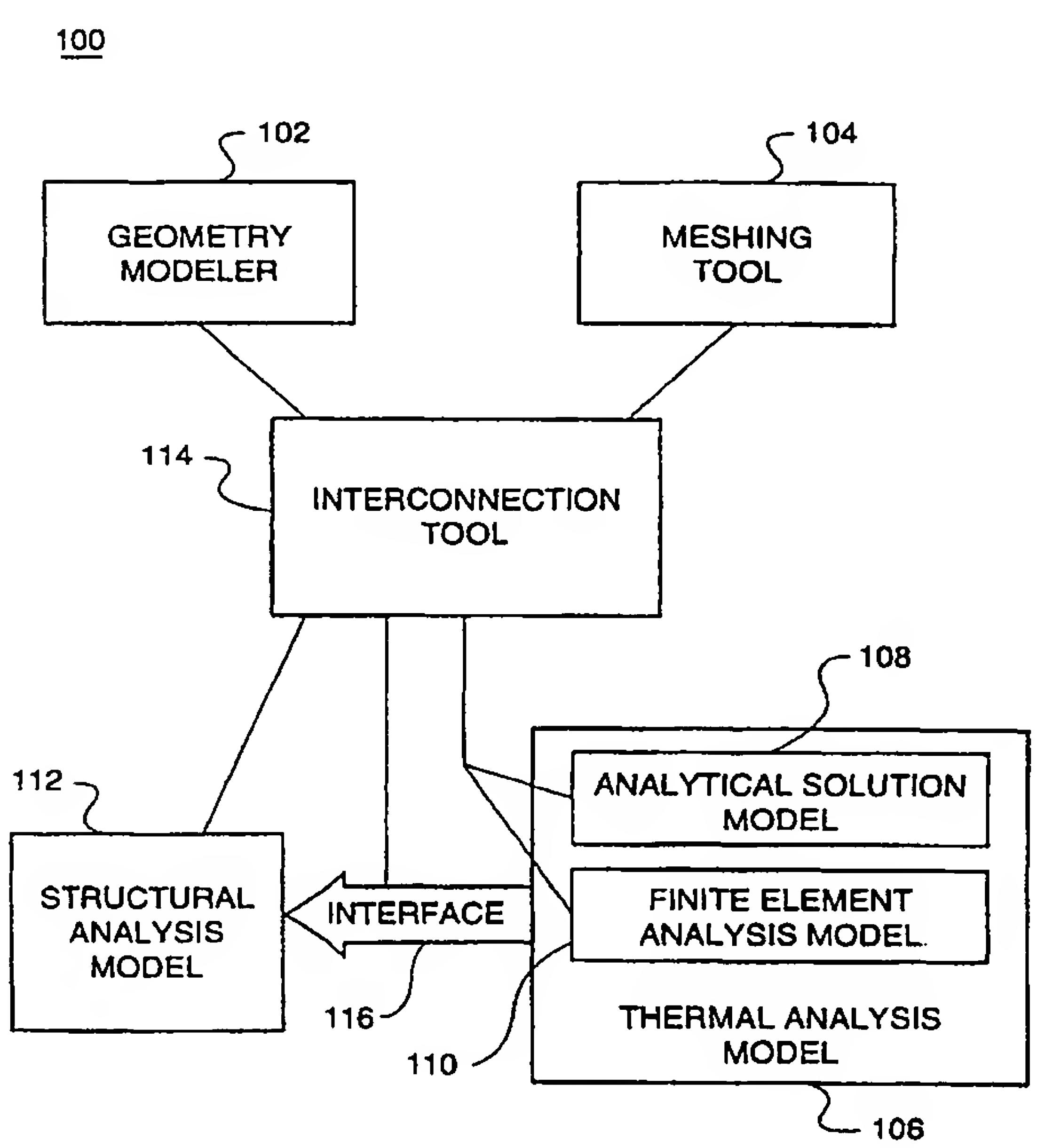
(54) Title: METHOD AND APPARATUS FOR PROVIDING A SIMULATION OF A WELDING PROCESS USING INTEGRATED MODELS



(57) Abstract: A method and apparatus for providing a simulation of a welding process using integrated models (100) which are interconnected by an interconnection tool (114) to determine stresses and distortions of a material being welded. The method and apparatus includes determining a model of a geometry of a set of materials to be welded, defining a set of coordinates of elements and nodes of the geometry model (102) for a finite element analysis mesh, delivering the finite element analysis mesh coordinates to a thermal analysis model (106), the thermal analysis model (106) including an analytical solution model (108) and a finite element analysis model (110), and determining a thermal analysis of the welding process, the thermal analysis responsively providing a thermal history of the welding process. The method and apparatus further includes delivering the thermal history of the welding process to a structural analysis model (112), and providing a structural analysis of the welding process as a function of the thermal history.

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Description

METHOD AND APPARATUS FOR PROVIDING A SIMULATION OF A WELDING PROCESS USING INTEGRATED MODELS

Technical Field

This invention relates generally to a method and apparatus for modeling a welding process and, more particularly, to a method and apparatus for integrating models for a welding process to perform a thermal and structural analysis of the process.

Background Art

The process of welding materials has some amount of detrimental effect on the materials being welded. For example, materials being welded are subjected to residual stresses and distortions due to the extreme heat caused by the weld process.

In the past, attempts have been made to analyze and determine the effects of heat on materials from the welding process. One method in particular, the finite element method (FEM), uses finite element analysis to model the weld process, and has been widely used to analyze the thermal effects of welding. However, FEM can be extremely cumbersome to implement and very costly.

Another method used to determine the effects of heat on materials from the welding process incorporates an analytical solution to determine the thermal history of the welding process. For example,

analytical solutions have been developed which use the superposition of point heat source solutions. These methods generally do not require the extremely cumbersome finite element analysis techniques previously used, and therefore provide a much more rapid analytical solution procedure. However, analytical methods do not account for such features as weld joint geometry. Furthermore, it may be desired to use both types of thermal models for some applications. For example, an analytical based model may be used for providing rapid, global solutions, and the FEM may be used to provide accurate temperature models for local areas of concern.

The present invention is directed to overcoming one or more of the problems as set forth above.

Disclosure of the Invention

In one aspect of the present invention a method for providing a simulation of a welding process using integrated models is disclosed. The method includes the steps of determining a model of a geometry of a set of materials to be welded, defining a set of coordinates of elements and nodes of the geometry model for a finite element analysis mesh, delivering the finite element analysis mesh coordinates to a thermal analysis model, the thermal analysis model including an analytical solution model and a finite element analysis model, and determining a thermal analysis of the welding process, the thermal

analysis responsively providing a thermal history of the welding process. The method further includes the steps of delivering the thermal history of the welding process to a structural analysis model, and providing a structural analysis of the welding process as a function of the thermal history.

Brief Description of the Drawings

Fig. 1 is a block diagram illustrating a preferred embodiment of the present invention; and

Fig. 2 is a flow diagram illustrating a preferred method of the present invention.

Best Mode for Carrying Out the Invention

Referring to Fig. 1, a block diagram illustrating a preferred embodiment of a set of integrated models 100 for performing a simulation analysis of a welding process is shown. The integrated models 100 work together to determine stresses and distortions of a material which is welded in the welding process. The stresses and distortions have an adverse effect on the strengths and characteristics of the material. Therefore, it is desired to model the stresses and distortions, and use the information from the models to determine methods which may minimize the adverse effects of welding.

In the preferred embodiment, an interconnection tool 114, such as a graphical user interface (GUI), interconnects the models into an integrated network of working models to determine

stresses and distortions of the material. The interconnection tool 114 is preferably computer-based and may be configured to operate autonomously, through manual intervention, or some combination of the two modes. For example, the interconnection tool 114 may coordinate the modeling functions while displaying the status and results to a human, who may override the system or input additional information at any desired time.

A geometry modeler 102 determines the geometry model for the materials to be welded. Preferably, the geometry modeler 102 simplifies the geometry by removing unnecessary features of the materials from the model. Examples of such features include, but are not limited to, chamfers, holes, slight irregularities, and the like.

The geometry model data is then delivered to a meshing tool 104. The meshing tool 104 is used to generate a finite element analysis mesh, preferably by defining coordinates for elements and nodes which constitute the mesh. Finite element analysis techniques which use mesh coordinates are well known in the art and will not be described further.

A thermal analysis model 106 is used to perform a thermal analysis of the materials during the welding process. In the preferred embodiment, the thermal analysis model 106 includes at least two models. An analytical solution model 108 provides a rapid analytical solution of the thermal process, i.e., welding process, for a global solution of

distortions caused by the welding process. A finite element analysis model 110 provides local detailed analysis of residual stress from the welding process.

In the preferred embodiment, the analytical solution model 108 determines solutions of point heat sources, the point heat sources being obtained from heat input based on welding processes and reflected heat sources determined from adiabatic boundary conditions of the material. The total analytical solution is determined from superposition of all the point heat sources. The principle of obtaining reflected heat sources from adiabatic boundary conditions is well known in the art and will not be discussed further. The analytical solution model 108 provides a rapid solution for the complete welding process. However, the solution is not highly detailed. Therefore, the analytical solution model 108 is typically used when a fast, global solution is desired, and a high degree of detail is not needed.

The finite element analysis model 110 employs numerical computations of conditions at each of the desired node and element coordinates of the finite element analysis mesh. The finite element analysis model tends to be computationally lengthy and intensive. Therefore, the finite element analysis model 110 is generally used only when a detailed analysis of a specific portion of the model is desired.

The information from the thermal analysis model 106 is compiled into a thermal history and

delivered to a structural analysis model 112. In addition, the finite element mesh provided by the meshing tool 104 is delivered to the structural analysis model 112. The interconnection is automatically established in the interconnection tool 114. In the preferred embodiment, the thermal history is delivered from the thermal analysis model 106 to the structural analysis model 112 by way of an interface module 116. Preferably, the interface module 116 is automated from the interconnection tool 114 and is adapted to seamlessly connect the thermal solution from the analytical solution model 108, the finite element analysis model 110, or both, to the structural analysis model 112.

The structural analysis model 112 provides further analysis of the materials during the welding process. Typically, the behavior of the material during welding is analyzed and modeled. Examples of features analyzed include, but are not limited to, melting and remelting of the material, phase transformation of the material, cyclic effects of multiple weld passes, and the like. The stresses and distortions of the material are determined by the structural analysis model. Preferably, the determined stresses and distortions may be further analyzed and subsequently used to modify the welding process to reduce the adverse effects of the extreme heat associated with welding.

Industrial Applicability

As an example of an application of the present invention, reference is made to Fig. 2, a flow diagram illustrating a preferred method of the present invention.

In a first control block 202, a model of the geometry of a set of materials to be welded is determined. In a second control block 204, a set of coordinates of elements and nodes of the geometry model is defined for a finite element analysis mesh. In a third control block 206, the finite element analysis mesh coordinates are delivered to a thermal analysis model 106. In the preferred embodiment, the thermal analysis model 106 includes an analytical solution model 108 and a finite element analysis model 110.

In a fourth control block 208, a thermal analysis of the welding process is determined as a function of at least one of the analytical solution model 108 and the finite element analysis model 110. The thermal analysis preferably provides a thermal history of the welding process. In a fifth control block 210, the thermal history of the welding process is delivered to a structural analysis model 112. In a sixth control block 212, a structural analysis of the welding process as a function of the thermal history is provided. Preferably, the structural analysis includes information related to stresses and distortions caused by the welding process. This information may be used to develop methods and

techniques to modify the welding process to minimize the stresses and distortions produced during subsequent welds.

Other aspects, objects, and features of the present invention can be obtained from a study of the drawings, the disclosure, and the appended claims.

Claims

1. A method for providing a simulation of a welding process using integrated models (100), the integrated models (100) being interconnected by an interconnection tool (114) to determine stresses and distortions of a material being welded, including the steps of:

determining a model of a geometry of the material;

defining a set of coordinates of elements and nodes of the geometry model (102) for a finite element analysis mesh;

delivering the finite element analysis mesh coordinates to a thermal analysis model (106), the thermal analysis model (100) including an analytical solution model (108) and a finite element analysis model (110);

determining a thermal analysis of the welding process as a function of at least one of the analytical solution model (108) and the finite element analysis model (110), the analytical solution model (108) being adapted to provide a thermal history of the welding process for a global distortion analysis, and the finite element analysis model (110) being adapted to provide a thermal history of the welding process for a detailed residual stress analysis;

delivering the thermal history of the welding process to a structural analysis model (112); and

providing a structural analysis of the welding process as a function of the thermal history.

2. A method, as set forth in claim 1, wherein providing a thermal history of the welding process for a detailed residual stress analysis includes the step of providing a thermal history of the welding process for a specific portion of the welding process.

3. A method, as set forth in claim 1, wherein providing a structural analysis of the welding process includes the step of modeling a set of characteristics of the materials being welded during the welding process.

4. A method, as set forth in claim 3, wherein characteristics of the materials include residual stresses and distortions.

5. A method, as set forth in claim 1, wherein determining a thermal analysis of the welding process as a function of the analytical solution model (108) includes the steps of:

determining a set of adiabatic boundary conditions of the material being welded;

determining a set of reflected heat sources as a function of the adiabatic boundary conditions;

determining a set of point heat sources as a function of the reflected heat sources; and

determining a total analytical solution from superposition of the point heat sources.

6. A method, as set forth in claim 1, wherein determining a thermal analysis of the welding process as a function of the finite element analysis model (110) includes the step of determining a set of numerical computations of conditions at each desired node and element coordinate of the finite element analysis mesh.

7. A method, as set forth in claim 1, wherein delivering the thermal history of the welding process to a structural analysis model (112) includes the step of delivering the thermal history by way of an interface module (116).

8. An apparatus for providing a simulation of a welding process using integrated models (100), the integrated models (100) being interconnected by an interconnection tool (114) to determine stresses and distortions of a material being welded, comprising:

a geometry modeler (102) adapted to determine a model of a geometry of the material;

a meshing tool (104) adapted to define a set of coordinates of elements and nodes of the geometry model (102) for a finite element analysis mesh;

a thermal analysis model (106) adapted to receive the finite element analysis mesh, determine a thermal analysis of the welding process, and

responsively provide a thermal history of the welding process, wherein the thermal analysis model (106) includes:

an analytical solution model (108) adapted to provide a thermal history of the welding process for a global distortion analysis; and

a finite element analysis model (110) adapted to provide a thermal history of the welding process for a detailed residual stress analysis; and

a structural analysis model (112) adapted to provide a structural analysis of the welding process as a function of the thermal history.

9. An apparatus, as set forth in claim 8, wherein the interconnection tool (114) is a graphical user interface.

Fig. 1

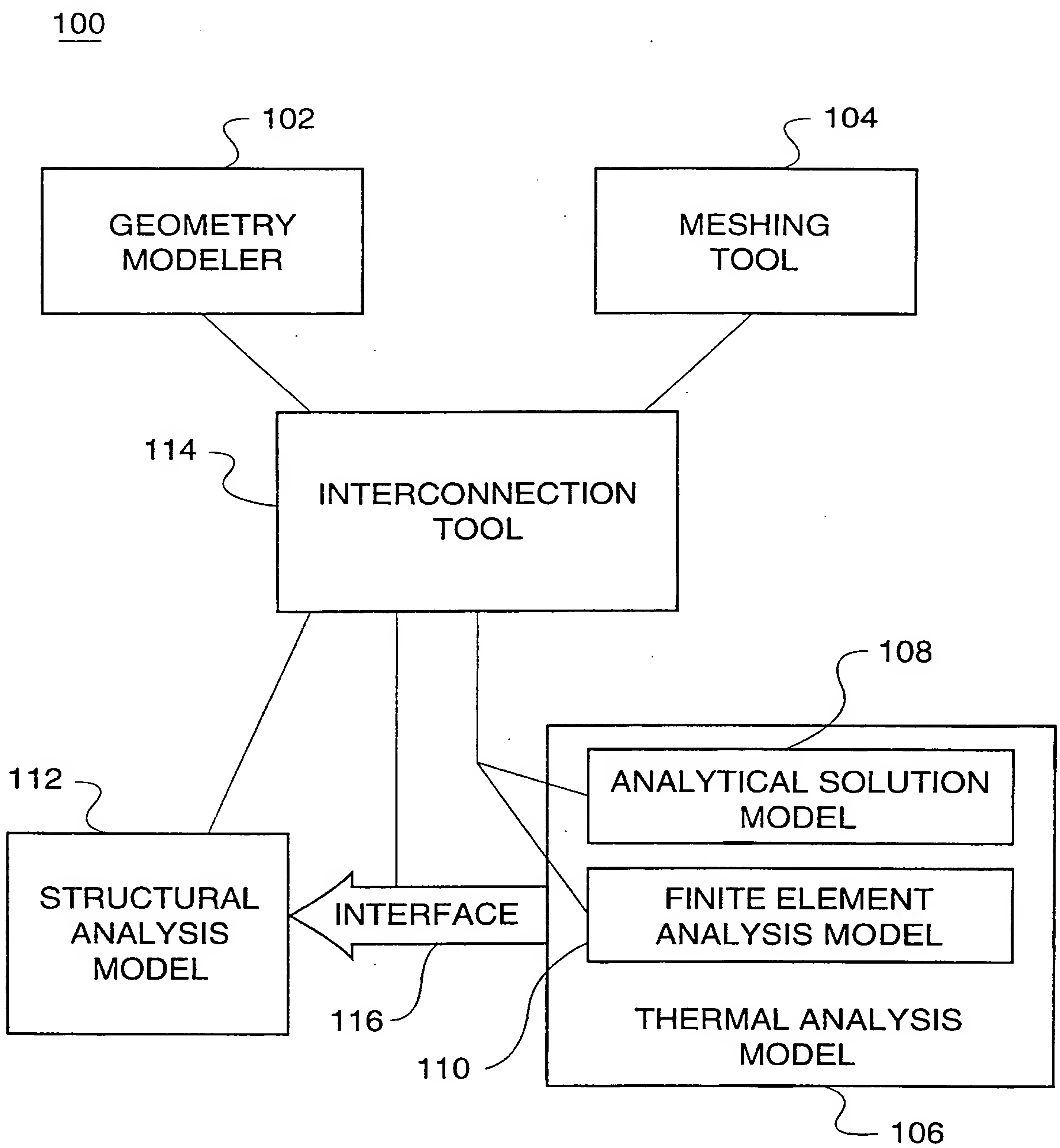
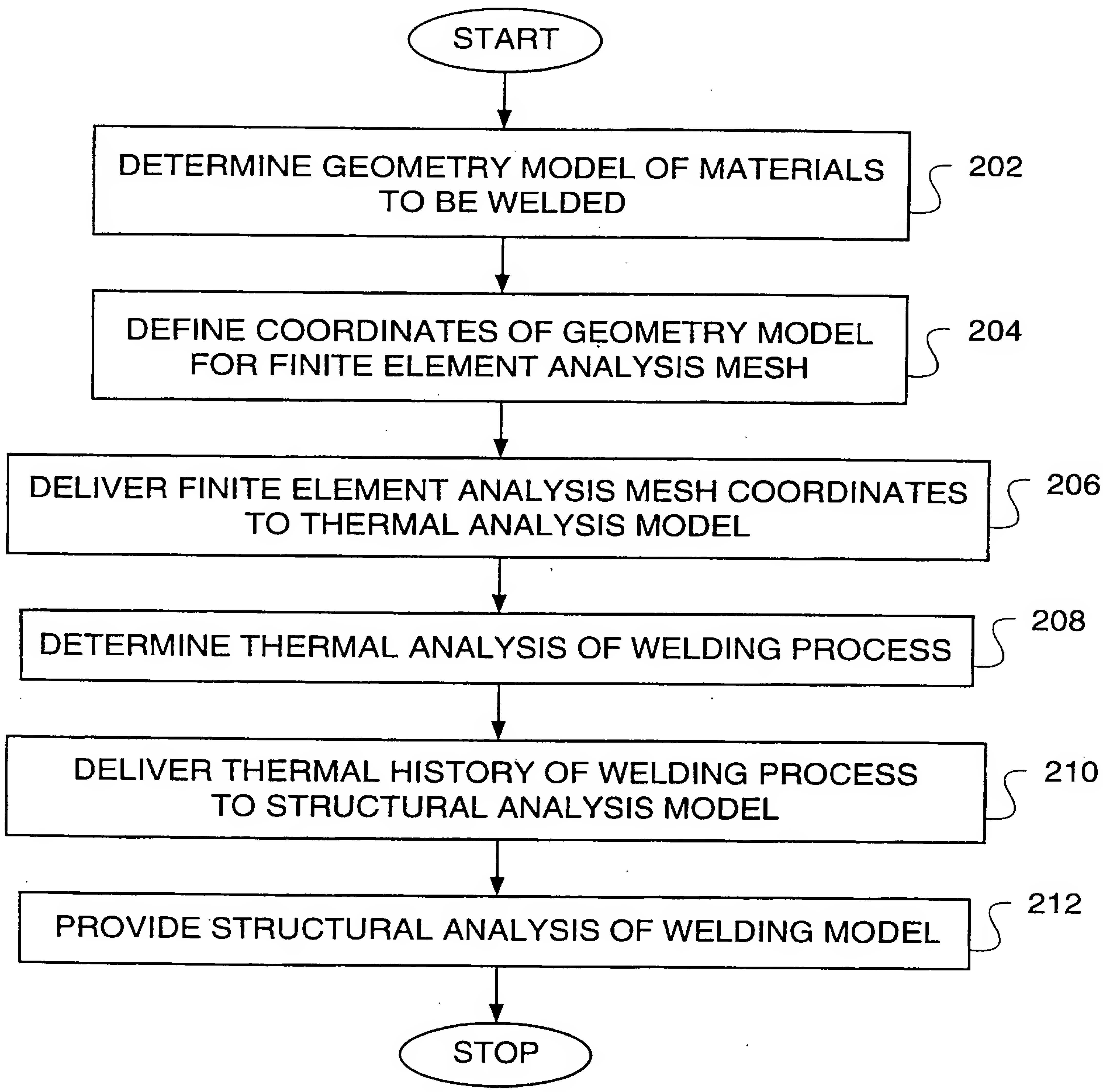

100
102
104
GEOMETRY MODELER
MESHING TOOL
114
INTERCONNECTION TOOL
108
112
ANALYTICAL SOLUTION MODEL
STRUCTURAL ANALYSIS MODEL
INTERFACE
FINITE ELEMENT ANALYSIS MODEL
116
110
THERMAL ANALYSIS MODEL
106

Fig. 2


START
DETERMINE GEOMETRY MODEL OF MATERIALS TO BE WELDED
202
DEFINE COORDINATES OF GEOMETRY MODEL FOR FINITE ELEMENT ANALYSIS MESH
204
DELIVER FINITE ELEMENT ANALYSIS MESH COORDINATES TO THERMAL ANALYSIS MODEL
206
DETERMINE THERMAL ANALYSIS OF WELDING PROCESS
208
DELIVER THERMAL HISTORY OF WELDING PROCESS TO STRUCTURAL ANALYSIS MODEL
210
PROVIDE STRUCTURAL ANALYSIS OF WELDING MODEL
212
STOP

INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B23K37/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

INSPEC, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	D. ISCHENKO AND R.N. IBRAHIM: "Development of new welding pattern in order to minimise distorsions in marine structure" KEY ENGINEERING MATERIALS, vol. 145-149, 1998, pages 859-864, XP000944978 the whole document ---	1-9
A	"Finite element simulation and measurement of welding residual stresses" MODELLING AND SIMULATION IN MATERIALS SCIENCE AND ENGINEERING, vol. 2, no. 4, 1994, pages 845-864, XP000944986 the whole document -----	1-9

☐ Further documents are listed in the continuation of box C.

☐ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
20 December 2000	05/01/2001

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